# MINISTRY OF WATER AND IRRIGATION
**Water Resource Policy Support**

*Wadi Zarqa*

# OPTIONS FOR WATER REUSE IN WADI ZARQA & FROM OTHER AMMAN-ZARQA SOURCES

## WATER REUSE COMPONENT

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# ABBREVIATIONS

| | |
|---|---|
| ARD | Associates in Rural Development |
| AZB | Amman-Zarqa Basin |
| BMP | Best Management Practices |
| $BOD_5$ | Biochemical Oxygen Demand, Five Day |
| COD | Chemical Oxygen Demand |
| DA | Development Area |
| DO | Dissolved Oxygen |
| ECC | Economic Consultative Council |
| FCC | Fecal Coliform Count |
| GAP | Good Agricultural Practices |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| GTZ | German Technical Cooperation |
| HL | Highlands |
| HRZ | Hashemite-Rusefieh-Zarqa area |
| IAS | Irrigation Advisory Service |
| IRG | International Resources Group |
| JICA | Japanese International Cooperation Agency |
| JV | Jordan Valley |
| JVA | Jordan Valley Authority |
| $Km^2$ | Square Kilometers |
| KTR | King Talal Reservoir |
| LEMA | Lyonaise des Eaux Management-Amman |
| LIMS | Laboratory Information Management System |
| $m^3$ | Cubic meter |
| M&I | Municipal and Industrial |
| MCM | Million cubic meters |
| MOA | Ministry of Agriculture |
| MOH | Ministry of Health |
| MWI | Ministry of Water and Irrigation |
| NCARTT | National Center for Agriculture Research and Technology Transfer |
| NIR | Net Irrigation Requirements |
| NPW | Net Present Worth |
| NRA | Natural Resources Authority |
| RA | Rapid Appraisal |
| RS | Remote Sensing |
| SO | Stage Office |
| SS | Suspended Solids |
| TDS | Total Dissolved Solids |
| TO | Task Order |
| UFW | Unaccounted for Water |
| USAID | United States Agency for International Development |
| WAJ | Water Authority of Jordan |
| WRPS | Water Resources Policy Support |
| WSP | Waste Stabilization Ponds |
| WWTP | Wastewater Treatment Plant |

# EXECUTIVE SUMMARY

This report present the investigations and studies into the present and potential for water reuse for agriculture along Wadi Zarqa, and opportunities for water reuse with effluent from the other Amman-Zarqa sources. Furthermore, the report presents the present and future demand for recycled water along the wadis and at the minor wastewater treatment plants.

The main conclusions from these investigations are:

- The health-based cropping restrictions in the wadi are not fully enforced. Approximately 4,000-dunums of vegetables are grown in the vicinity of the wadi water, which is mainly comprised of effluent. In addition to the real risks, the perception to the general public jeopardizes the domestic and export markets.

- Although further land (3,000-dunums) could be developed for irrigation in the wadi, much of this was historically irrigated, and would come back into production if markets improved and health-based cropping restrictions were lifted. Using the wadi for conveyance and pumping to each farm separately is, by far, the least expensive option.

- Land for the further development of irrigated agriculture is also constrains reuse from the minor wastewater treatment plants. However, both Baq'a and, to a lesser extent, Jerash present potential opportunities for exchanging recycled water for fresh water sources. Detailed feasibility studies are required.

## Existing Conditions

Using satellite imagery to identify the areas of irrigation in wadis Dhuleil and Zarqa, and the side-wadis, 41 farmers or farm managers were interviewed, to determine water management practices, their understanding of the water quality, the water-related constraints and their likely response to increased supplies in the wadi.

Of the farms being irrigated from the wadi water, none indicated that water quantity was an issue, and would not change their present cropping practices if more water was available in the wadi. The reported reduction in irrigated areas was, according to the respondents, due to the restrictions on vegetable production or poor markets, rather than availability of water.

Farmers reported a wide variety of issues relating to the poor water quality in the wadi. These issues include drying of the leaves on the olive trees, reduced life span of alfalfa crops, and reduced life span of stone fruit trees. A few recognized the value of the nutrient rich water on better yields for alfalfa and stone fruits. Many farmers' linked increased pests and diseases. However, some of the same pests (nematodes and fusarium) were reported where the farm did not have access to wadi water.

An improvement in the quality of the water in the wadi would result in many farmers growing a "…variety of vegetables…", assuming the Government would allow this. However, a number said that they would not change their cropping pattern, as the issues with crop selection did not lie with the water quality, rather with the poor market for produce.

Concurrent to the field investigation, the satellite imagery was used to estimate the area of irrigated land, and estimate the proportion of irrigated vegetables that may be grown with some portion of effluent. The total area of presently irrigated land, which could be using water from As Samra wastewater treatment plant, extends to around 17,000-dunums (1,700-ha), of which roughly 4,400-dunums (440-ha) or 26 percent are in vegetables.

There is a clear risk associated with using water from the wadi to irrigate vegetables, many of which can be eaten raw. Few respondents admitted such practices, arguing that the vegetables grown in the wadi were done so with spring water. However, there is strong evidence to the contrary. If current standards were being adhered to, the level of risk to which the public and the farm workers are exposed would be many orders of magnitude lower than at the present time. Furthermore, the proximity of water in the wadi, which smells and looks foul, and the irrigated vegetable crops on the riparian lands, leaves even the most casual visitor with a very poor impression of the produce that is likely reaching the market.

The risks to farm workers, consumers and markets of the water reuse practices in wadi Zarqa are unacceptably high. Furthermore, the implementation of the As Samra improvements will not, by itself, bring the microbiological quality of the water in the wadi to comply with the Jordanian Standards for irrigation of vegetable crops to be eaten cooked.

The anticipated improvements at the As Samra wastewater treatment facility should reduce such perceptions. However, the actual risk to public health will remain high as fecal coliform levels in the wadi are often high even discounting the impact of the effluent from As Samra. The socio-economic impact of these practices will be considered further under a separate activity. However, at this time, it is evident that the practice of irrigating vegetables in wadis Dhuleil and Zarqa, whether the water source is the wadi or adjacent springs and wells, seriously jeopardizes the market, export and domestic, for all vegetable crops grown in Jordan.

The risk reduction measures that should be implemented in wadi Zarqa are:

- Completion of the new facilities at As Samra.
- Renewed efforts to effect the ban on the growing of any raw-eaten crops, whether irrigated with wadi, spring or well water.
- Training program for farm workers to minimize their exposure to health issues associated with irrigating with water from the wadi.
- Development and implementation of a management plan to reduce the microbiological contamination entering wadi Zarqa and wadi Dhuleil from sources other than the wastewater treatment plant.

Offsetting measures to facilitate the viability of irrigated agriculture in wadi Zarqa:

- Revise the present standards (see MWI/ARD, 2001c) for irrigation with recycled water to minimize the risk yet allow the maximum range of crops to be grown.
- Develop and disseminate information on the relative viability of specific crops using wadi Zarqa water, such as varieties of citrus better able to withstand the prevailing salinity, nitrogen and chloride levels in the wadi water. It should be noted that with the improvements scheduled for As Samra the nitrogen levels will be reduced.

## Water Reuse Options in Wadi Zarqa

The basic option for further reuse of water in wadi Zarqa is further development of irrigated agriculture or forestry. Examination of existing maps and the satellite imagery indicates that land is limited.

Two basic variations considered were to develop irrigated agriculture or forestry using the wadi itself to convey the water and have the farmers pump from the wadi, as is done now, and the other is to construct a conveyance system to deliver water to the areas to be developed. The capital costs of the conveyance system would be nearly twenty times more than the present practice, with little appreciable additional benefit.

The intensification and expansion of irrigated agriculture on the riparian lands in wadis Dhuleil and Zarqa have some merit, although the area available is limited to less than 3,000-dunums. The present economic and regulatory enforcement situation, which would also apply for development of irrigated agriculture in the highlands, clearly limit the incentives for such developments.

The gross irrigation and leaching requirements in the wadi (zone #7) are presented in Table 1. For and irrigated area of 17,000-dunums, as is the case now, the total water requirement is estimated to be 19 M-m$^3$ per annum, rising to 22 M-m$^3$ per annum if all the "irrigable" land was brought into production. Some of this water demand is met by springs along the wadi.

**Table 1.** Gross irrigation requirement and leaching requirements per dunum for each month

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | | TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GIR | m^3/dn | 0 | 0 | 31 | 93 | 140 | 148 | 143 | 145 | 119 | 78 | 10 | 0 | | 907 |
| Leaching | m^3/dn | 48 | 48 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38 | 48 | | 200 |
| Total | m^3/dn | 48 | 48 | 48 | 93 | 140 | 148 | 143 | 145 | 119 | 78 | 48 | 48 | | 1,107 |

## Options at Other Wastewater Treatment Plants

The other existing wastewater treatment plants in the Amman-Zarqa basin are Jerash (east), Abu Nuseir and Baq'a (MWI/ARD, 2000a). There are further wastewater treatment plants planned for Jerash (west) and for Zarqa, located downstream of the As Samra plant. The Zarqa plant is considered as part of water reuse associated with the As Samra plant in the main Wadi Zarqa and, therefore, has already been discussed in Chapter III.

At Jerash, the bulk of the relatively good quality effluent is being used by one larger (~174-dunums) farm. The total irrigated area in the Jerash wadi extends to approximately 2,000-dunums, with the bulk of these lands being irrigated by fresh water from springs upstream. There is limited room for further development of irrigated agriculture in the wadi. However, as the spring upstream has already been developed for domestic use, as increased supplies of effluent become available, there is likely to be a demand from those lands that are presently using spring water. Any remaining effluent will continue down to KTR.

At Abu Nuseir it is proposed to use the effluent stream for irrigation of trees extending to approximately 850-dunums (JICA, 2000). Presently, effluent, minus losses, flows via wadi Zarqa to KTR. The projected volumes of effluent generated at this plant will not be sufficient to meet the demand from850-dunums.

Presently the only water reuse from Baq'a wastewater treatment plant is at two farms downstream of the effluent conveyance pipe, near King Talal Reservoir. There is no suitable land within the immediate vicinity of the plant. However, immediately to the East of the plant is the Baq'a valley where irrigated vegetables (around 4,000dunums), using groundwater, are grown. This presents a potential opportunity for exchange of recycled water with relatively low development costs, thereby freeing up fresh water for domestic use. There are many important issues with such a development, including the potential threat to the groundwater, the marketing concerns, the impact on cropping patterns and the acceptability by the present users. However, the value of the groundwater would justify investment further treatment of the wastewater, farmer education and so forth.

Considering the above, the range of demands for recycled water from the minor wastewater treatment plants, that is from no further development to implementation of the developments discussed above, are presented in Table 2.

**Table 2.** Expected recycled water requirements at the minor wastewater treatment facilities for scenario without further development, and scenario with development.

| WWTP | WATER REQUIREMENTS | | | | |
|---|---|---|---|---|---|
| | Present | Future w/o | Future with | | |
| | | | 2005 | 2010 | 2025 |
| Abu Nuseir | 0 | 0 | 0.4 M-m$^3$ | 0.45 M-m$^3$ | 0.6 M-m$^3$ |
| Baq'a | 0 | 0 | 2.2 M-m$^3$ | 4.4 M-m$^3$ | 4.4 M-m$^3$ |
| Jerash | 0.6 M-m$^3$ | 0.6 M-m$^3$ | 1.3 M-m$^3$ | 2.2 M-m$^3$ | 2.2 M-m$^3$ |
| Jerash West | 0 | 0 | 0 | 0 | 0 |

## Recommendations

Considering the above, the recommendations with respect to water reuse in the wadi and from the minor wastewater treatment plant can be subdivided into reducing misuse, improving economic returns from irrigated agriculture, and replacement of fresh water presently used for agriculture. Further intensification of irrigated agriculture in the wadis will occur if irrigated agriculture is more viable.

### Reduce Misuse of Recycled Water In Wadi Zarqa & Tributaries

1. The present ban on any vegetables or fruit that are not grown on trees should be extended to all riparian lands in wadi Zarqa and to the side wadis with a wastewater treatment plant upstream, no matter what the water source.

2. When the fecal coliform levels in the wadi are reduced to comply with the Jordanian Standards (below 1000-MPN), the growing of vegetables and fruit to be eaten cooked could be allowed, thereby allowing farmers, particular small-scale operations, further opportunities to make a positive return.

3. The reduction of fecal coliform in the wadi requires implementation of the new facilities at As Samra, and implementation of a plan to comprehensively control other sources of microbiological contamination to the wadi. The investigation of these other sources of microbiological contamination is an urgent requirement.

### Improving Economic Returns from Water Reuse In Agriculture

4. Provide farmers with more information on crop selection with respect to the quality of the wadi water, such as the negative impact of the salts and chlorides on the citrus and stone fruits. Develop recommendations on crops and specific varieties that will provide good returns with the quality of water anticipated in the wadi.

### Replacement of Fresh Water Presently Used For Agriculture

5. Investigate and, if found to be feasible, implement exchanges of recycled water from the minor wastewater treatment facilities, for groundwater and/or spring water presently used for agriculture. The two main areas to be investigated are Baq'a and Jerash.

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Many people patiently provided their insights into the history and present situation in Wadi Zarqa and voiced their concerns with respect to water use and water reuse in wadi. The farmers deserve special mention. Faced with the challenges of irrigation with poor quality water, they took time to relate their experiences and concerns.

Finally, the support of the United States Agency for International Development (USAID) Mission in Jordan, and the Associates in Rural Development (ARD, Inc.) team, in Jordan and Vermont, is highly appreciated.

# CHAPTER I
# INTRODUCTION

This report present the investigations and studies into the:

- present and future water reuse for agriculture along Wadi Zarqa, and
- opportunities for water reuse from other Amman-Zarqa sources.

## I.1. BACKGROUND & OBJECTIVES

### I.1.1. Water Reuse for Agriculture Along Wadi Zarqa

Treated effluent is presently discharged from As Samra into Wadi Dhuleil, a tributary of Wadi Zarqa. With the overloaded condition of the wastewater treatment facility at As Samra, the present quality of this effluent is poor (MWI/ARD, 2000a).

The waters from Wadi Dhuelil and from Wadi Zarqa, which at times of the year are fully comprised of effluent, are used to irrigate a variety of crops, including those to be eaten raw, on riparian lands in the Wadi. The risks with regards to human health and public confidence need to be addressed are high.

The objectives of this sub-activity is to characterize the present water reuse for irrigated agriculture in Wadi Zarqa, and determine options for further development.

### I.1.2. Water Reuse Opportunities From Other Amman Zarqa Basin Sources

Most of the treated wastewater of Jordan will originate at the As Samra wastewater treatment plant. Nevertheless, a significant amount of effluent is generated by other wastewater treatment plants in the basin (MWI/ARD, 2000a).

The main objective of the activity on water reuse from other Amman-Zarqa sources is to review existing plans for future use of wastewater at the various wastewater treatment plants in the Amman Zarqa Basin, and identify potential options.

## I.2. SCOPE & LIMITATIONS

As mentioned above, the scope of this work is the present and future of water reuse for irrigated agriculture on the riparian lands between As Samra and King Talal Reservoir, and the potential future water reuse for irrigated agriculture from the minor wastewater treatment facilities in the Zarqa basin.

The primary areas of interest are where water that has originated from the As Samra wastewater treatment plant may be used, that is irrigated farms on the riparian lands of wadi Dhuleil and wadi Zarqa downstream of the plant. Also of interest are the areas where effluent from the minor wastewater treatment plants in the basin could be used.

These investigations do not include riparian lands downstream of KTR, which, as they are using KTR water, will be considered as part of the Jordan Valley investigations.

These investigations are concerned with the use of water originating from the wastewater treatment plants in the Amman-Zarqa Basin. However, the surface water resources in the Basin are contaminated from other sources (point and non-point), specifically intensive livestock activities, industry and the urban development (Amman) upstream. Such contamination has to be addressed in managing the water resources of the Amman-Zarqa basin.

# CHAPTER II
# PRESENT WATER REUSE IN WADI ZARQA

## II.1. Field Investigations & Interviews

To guide the field visits, a set of questions was developed. After field testing, the number of questions was reduced and finalized (see Appendix A).

Satellite imagery was used to identify the major areas of irrigation on the riparian lands of wadis Dhuleil and Zarqa, and the side-wadis, including As Sleyhi, Ar Rumman, Ar Rumaymin, Jerash, and Qunia spring. Dhuleil, Zarqa and Jerash and Sleyhi all receive effluent discharges, where the others do not. Using these images, the field visits were conducted to sample from farms in the main irrigated areas along the major wadis, and from the side-wadis. The farms visited are shown in Figure II.1. In all, 41 farms were visited and either the owner or the manager interviewed.

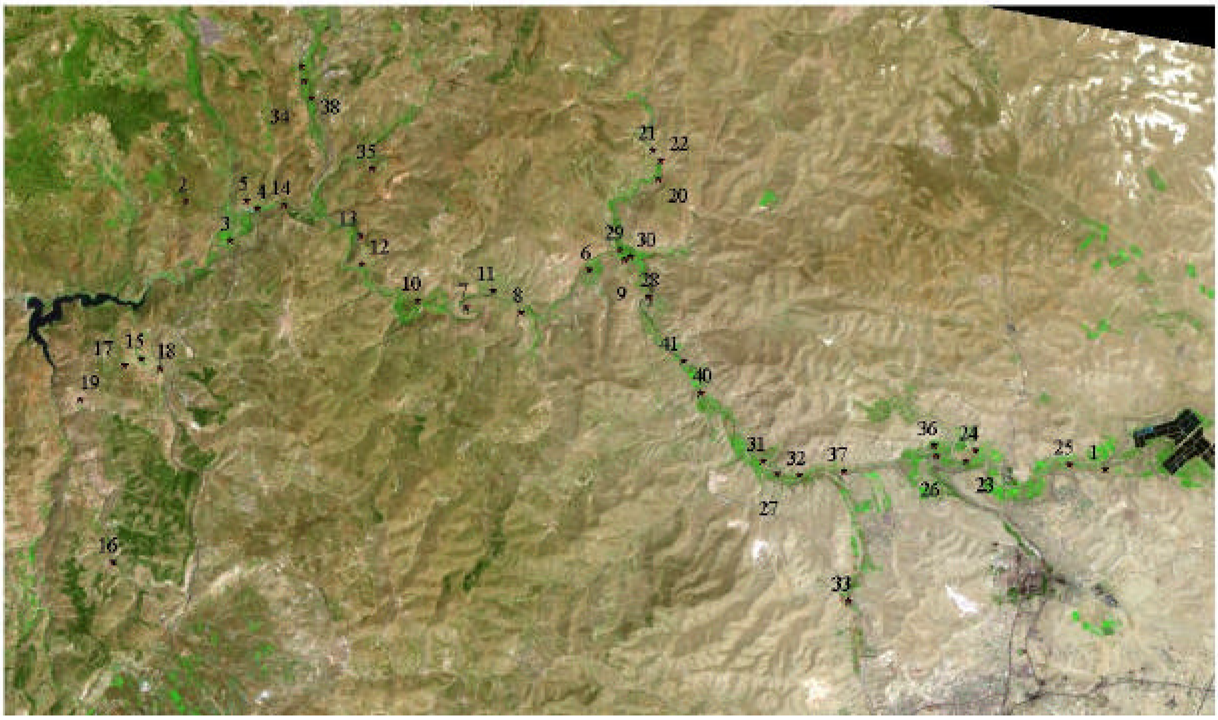

**Figure II.1.** Irrigated areas and farms visited in wadis Zarqa, Dhuleil and tributaries

Following completion of the visits by the team, the information gathered was entered into an ACCESS based database. These results are summarized in Appendix B, and discussed below. The information generated is also used when considering future water reuse in the wadi (see Chapter III).

The field-testing of the questions was conducted on October 19, 2000, and the investigations undertaken between October 23 and December 01, 2000.

## II.2. Characterization of Water Reuse

### *Wadis Dhuleil & Zarqa*

Water Quality

Farmers reported a wide variety of issues relating to the poor water quality in the wadi. These issues include drying of the leaves on the olive trees, reduced life span of aflalfa crops, and reduced life span of stone fruit trees. Some farmers reported that the water smells bad. On the other hand, some farmers recognized the value of the nutrient rich water on better yields for alfalfa and stone fruits.

Many farmers linked increased pests and diseases with the wadi water, including flies mosquitoes, rodents, viruses, bacteria, nematodes, fusarium and weeds (orobanche). However, some of these, including nematodes and fusarium, were reported by farmers that did not have access to wadi water. At this point, it is not possible to determine whether these problems are directly related to the quality of the wadi water.

One of the nurseries using the wadi water reported that some of the plants were sensitive to the constituent levels in the water.

Should the quality of the water in the wadi improve, the majority of the respondents indicated that they would grow a "…variety of vegetable…", assuming the Government would allow this. However, a number said that they would not change their cropping pattern, as the issues with crop selection did not lie with the water quality, rather with the poor market for produce.

Water Quantity

Of the farms being irrigated from the wadi water, none indicated that water quantity was an issue, except with regard to flooding, when pumping facilities could be washed away. None would change their present cropping practices if more water was available in the wadi. The reduction in irrigated areas that many of the farmers suggested were due to the restrictions on vegetable production or, to a lesser extent, poor markets, rather than availability of water.

Irrigation Management

A few farmers reported no problem with irrigation water management, whereas a relatively large number of smaller farmers reported the lack of an application network (trickle/drip system), which they cannot afford, as their major problem. However, a number of those with drip systems reported that clogging was their major water management related problem. This was restricted to farms using contaminated water. A few farmers did mention that these clogging problems had been addressed either by filtration and the use of acid, or, as in one case, by making their own drip lines with larger nozzles.

Other issues

A common concern of many of the farmers was the poor markets for many of the crops, including vegetables. Some, usually the smaller farmers, were seriously considering abandoning their farms because the returns they were generating were insufficient to support their families. Although such a response has to be treated with some sceptisism, the returns from irrigated vegetable production are not good under the present conditions (Shaner, 2000).

Many of the farmers voiced an interest in growing "…all kinds of vegetables…" when the quality of the water in the wadi improves.

### II.3. Classifying Irrigated Areas with Satellite Imagery

Concurrent to the field investigation described above, the team used satellite imagery to locate the presently irrigated lands, estimate the area of irrigated land, and develop an approximate estimate of the proportion of irrigated vegetables that could be grown with some portion of recycled water. Details of the analysis of the imagery are included in Appendix C.

### II.4. Impact on Public Health and Perception

Measuring the actual impact on public health of the misuse of treated effluent in the Wadi Zarqa area would be a large undertaking. However, there is clearly a risk associated with such practices.

Compliance with the existing Jordanian Standards and Regulations would significantly reduce the risk, although not remove it entirely. The standards and regulations are being examined under a separate activity in this project, and will consider the risks posed by the present standards and regulations. If current standards were being adhered to, the level of risk to which the public and the farm workers are exposed would be many orders of magnitude lower than at the present time.

The impact of the present irrigation practices in Wadi Zarqa on public perception are very significant. The association between the proximity of water in the wadi, which smells and looks foul, and the irrigated crops on the riparian lands, leaves any visitor with a very poor impression of the produce that could be reaching the market. The anticipated improvements at the As Samra wastewater treatment facility should reduce such perceptions. However, ironically, the actual risk to public health will remain high as fecal coliform levels in the wadi are often high even discounting the impact of the effluent from As Samra.

Interestingly, the Ministry of Health considers that vegetables or fruit grown close to the ground, whether to be eaten raw or not, are not allowed under the regulations. To a certain extent, with the high FCC levels in the wadi, this is true, but, according to the existing standards, no crops what-so-ever are allowed to be grown with effluent with FCCs above 1000 MPN.

### II.5. Socio-economic Impact on the Export Market

Detailed examination of the impact of present and future water reuse activities is to be conducted as a separate activity for the entire wadi Zarqa and Jordan Valley. This will include the specific impacts of the practices in wadi Zarqa.

However, at this time, it is evident that the practice of irrigating vegetables in wadis Dhuleil and Zarqa, whether the water source is the wadi or adjacent springs and wells, seriously jeopardizes the market, export and domestic, for all vegetable crops grown in Jordan.

# CHAPTER III
# FUTURE WATER REUSE IN WADI ZARQA

This chapter considers the likely response by irrigated agriculture in wadi Zarqa when the quantity of effluent discharged to the wadi increases and when the quality improves, the potential option for further irrigated agriculture use of recycled water in the wadi, and measures for reducing the risks associated with use of recycled water in wadi Zarqa.

### III.1. Increased Quantities and Improved Water Quality

#### *Quantity*

With respect to the anticipated increased quantity of effluent in the wadi, the farmers interviewed unanimously stated that the present quantity of water in the wadi was more than sufficient for their needs and their response to increased quantities would be "…do nothing…".

#### *Quality*

A number of the respondents pointed out that the area they presently irrigated was less than it had previously been. The reason for this change was the enforcement of the Jordanian Standards on irrigation with recycled water, which banned the irrigation of vegetables. In some cases farmers have replaced these vegetable crops with fodder, especially the larger farmers who have developed their own dairies. Also, farmers have planted tree crops (fruit and olives), although such options do not tend to be available to the smaller farmers.

Many respondents stated that they would grow more vegetables if the quality of the water in the wadi improved, assuming that they were allowed to under the Jordanian Standards.

### III.2. Further Options for Reuse

Considering the above, use of some of the projected increase in recycled water on the riparian wadi land could occur if the list of allowable crops were expanded to include vegetables. Whether this would occur to the extent of the historical maximum irrigated area is not certain, although under the present depressed pricing of farm produce it seems unlikely.

Expansion of irrigated area within the wadi, beyond that of the historical maximum, is even less likely under the present prevailing economic conditions. However, over the planning horizon being considered in the master plan, it would be a good assumption that agricultural economic conditions would improve.

## III.3. Risk Reduction

The reduction of risks to the farm workers and the consumers have to be the over-riding concerns with any future efforts related to water reuse in the Amman-Zarqa basin. As has been pointed out in chapter II above, the present risks are unacceptably high, especially considering the present poor microbiological quality of the water in the wadi. There is also the risk to the markets for the other producers in the country who are not using recycled water.

The risk reduction measures that should be implemented in wadi Zarqa are:

- Completion of the new facilities at As Samra.
- Total ban on the growing of any fruit or vegetables normally eaten raw whose edible parts may contact the irrigation water, whether irrigated with wadi, spring or well water.
- Training program for farm workers to minimize their exposure to health issues associated with irrigating with water from the wadi.
- Development and implementation of a management plan to reduce the microbiological contamination entering wadi Zarqa and wadi Dhuleil from sources other than the wastewater treatment plant.

Offsetting measures to facilitate the viability of irrigated agriculture in wadi Zarqa:

- Revise the present standards for irrigation with recycled water to specify the crops which can be grown, including fruit and vegetables whose edible portion does not come in contact with the water or that will not be eaten raw, such as eggplant.
- Develop and disseminate information on the relative viability of specific crops using wadi Zarqa water, such as varieties of citrus better able to withstand the prevailing salinity, nitrogen and chloride levels in the wadi water. It should be noted that with the improvements scheduled for As Samra the nitrogen levels will be reduced.

# CHAPTER IV
# WATER REUSE OPTION IN WADI ZARQA

## IV.1. Overview of Concept & Potential Location

The option proposed for wadi Zarqa is for the further development of irrigated agriculture or forestry within the wadi downstream of the As Samra wastewater treatment plant, or in the immediate vicinity of the facility.

There are two basic variations of this option. The first is to develop irrigated agriculture using the wadi itself to convey the water and have the farmers pump from the wadi, as is done now. The other is to construct a conveyance system, most likely a pipeline, to deliver water to the areas to be developed.

Although both of there variations will be discussed in some detail below, at the outset, a system which allows individual farmers the flexibility to turn on their water supply as needed (on-demand system) is much preferable, even if it comes at a higher cost. In theory, a system based on open-ended pipelines delivering to multiple users will result in savings in pumping costs but, in practice, are difficult to operate equitably.

## IV.2. Water & Land Resources

### IV.2.1. Water Resources

The recycled water resources for the further development of irrigated agriculture in wadi Zarqa are, as with the highlands irrigation options, those generated from As Samra and, possibly, Wadi Zarqa wastewater treatment plants. As detailed in MWI/ARD (2000a) and MWI/ARD (2000b), the volume of available effluent is expected to increase by a further 50 MCM/annum by the year 2010.

It is assumed that the improvement of the As Samra plant will be completed in 2005, and the quality parameters will be as projected in MWI/ARD (2000a). Quality levels are expected to be in compliance with the respective Jordanian Standards. Further treatment of the recycled water is not anticipated, although disinfection would be advisable, and filtration at the field level will be required for drip irrigation systems.

### IV.2.2. Land Resources

Limitations on land resources present one of the primary constraints to further development of irrigated agriculture in wadi Zarqa. With the advent of technologies such as drip irrigation, the expansion of irrigated agriculture onto what would once have been considered marginal lands (i.e. too steep) is now feasible. In the lower reaches of Wadi Zarqa and in Wadi Jerash, such as Jerash, parcels of relatively steep land are now being irrigated. In some of these cases farmers are pumping 50 to 100-m up the wadi side.

Unlike the highlands (MWI/ARD, 2000b), the potential land resources for irrigation are not contained in a large, homogeneous area, and, therefore, not easily interpreted from existing maps or images. Also, considering the examples already established in the wadi, land has been brought into production at significant development and/or operating cost.

Harza (1997) estimated that the total irrigable area in Wadis Dhuleil and Zarqa was around 15,000-dunnums, and that, from Ministry of Agriculture, the irrigated area in 1994 was 7,900-dunnums. The analysis of satellite imagery (see Appendix C) determined that the irrigated area in August 1999 was approximately 17,000-dunnums, including the area around the As Samra facility. Using the land classification results, available contour maps and further visits to the field, the team concluded that there may be the potential for no more than a further 3,000-dunnums in the wadi, that is a total of 20,000-dunnums of irrigable land. However, most of this land had at some time been irrigated and was now lying fallow. This correlates with the responses from the farmers, that some land was fallow because of low prices for produce

## IV.3. Cropping Patterns & Water Demands

### IV.3.1. Cropping Patterns

The selection of cropping patterns for irrigation options has been discussed in detail in the report (MWI/ARD, 2000b) on the highlands options and in the subsequent economic analysis (Shaner, 2000). This study uses the same basic approach and information, but also reflects the feedback that has been obtained since completing the draft report on the highlands options, and the information gathered during the farm interviews (see Chapter II).

The selection of a cropping pattern lies with the producer, who has to rationalize many variables to ensure that an acceptable financial return is made considering the many risks involved. The supply of water for irrigation is only one of the required inputs.

The two primary reasons for establishing a “design” cropping pattern are determination of the:

- economic and financial viability of irrigated agriculture under the specific conditions in the area;
- crop-water needs: thereby, defining the capacity of the pumping, conveyance, storage, distribution and application systems to meet those needs.

For the highlands options (MWI/ARD, 2000b), a preliminary list of crop categories (suitable, maybe and not suitable) for water reuse was developed, which considered the viability of the crop in the area, its present production in the area, its sensitivity to the projected concentration of constituents in recycled water and the crop’s compatibility with the Jordanian Water Reuse Standards. Following feedback from various sources, including Grattan (2000) on crop sensitivity, the revised crop categorization is shown below. Also, as discussed in Shaner (2000), the exclusion of surface irrigation techniques for applying recycled water is further restricting the crop selection, yet, the need for leaching will, by definition, also cause deep percolation of recycled water beyond the root zone.

**Table IV.1.** Proposed crop categories for water reuse (revised from MWI/ARD, 2000b)

| COMPLIANCE | | |
|---|---|---|
| **YES** | **MAYBE** | **NO** |
| Alfalfa[1] | Broccoli | Cabbage |
| Apples[2] | Citrus[3] | Carrot |
| Barley[1] | Cucumber | Cauliflower |
| Broad Beans | Green Beans | Celery |
| Dates | Pepper | Lettuce |
| Eggplant | Spinach | Radish |
| Flowers | | Strawberries |
| Forest | | Tomato |
| Garlic | | |
| Grapes | | |
| J_Malok | | |
| Melons | | |
| Okra | | |
| Onion[3] | | |
| Olives | | |
| Peaches[3] | | |
| Peas | | |
| Potato | | |
| Squash | | |
| Turnip | | |
| Wheat[1] | | |

[1]Crops not suitable for irrigation with drip or trickle.
[2]Crop added to category following feedback
[3]Crop is sensitive to salts and/or chloride, but is already grown with recycled water

### IV.3.2. Water Demands

To specify the design requirements of the water pumping, conveyance, storage, distribution and applications system, the expected crop water demands need to be determined. As discussed above, the system should provide sufficient flexibility to allow for changes in cropping patterns so as to allow the producer to respond to the realities of the markets. The system also needs to deliver sufficient water to leach salts from the root-zone.

The same basic approach that was used for the investigation of highlands options (MWI/ARD, 2000b) was used here, with adjustments for the difference in climate. The wadi is generally within agro-climatic zone #7, rather than zone #10, as was the case for the highlands. That is, the design crops-water-needs should allow for a mixture of shallow, medium and deep rooting crops. The basic design cropping pattern used is 30 percent shallow rooting (onions), 30 percent medium rooting (alfalfa) and 40 percent deep rooting (olives).

The two crop-water related parameters of interest, with respect to characterizing the design of the irrigation system, are the peak water demand, and the overall seasonal water demand. In this case, the peak gross irrigation requirement was taken as 1.1-lps/ha, the same as used in the highlands. The total water requirement, excluding leaching is 910-mm (9,100-$m^3$/ha) per annum, which would be distributed as shown in Figure IV.1.

### IV.3.3. Leaching Requirement

As detailed in MWI/ARD (2000b), the leaching requirement is approximately 200-mm. This does not account for salts added to the root zone by fertilizers nor the potential natural leaching by rainfall. The total water requirement is, therefore, 1,110-mm (11,100-$m^3$/ha) per annum.

It is assumed that leaching will be done in months when the crop-water demands are lower than peak. The distribution of gross irrigation requirements and leaching requirements are shown in Figure IV.1 and Table IV.1.

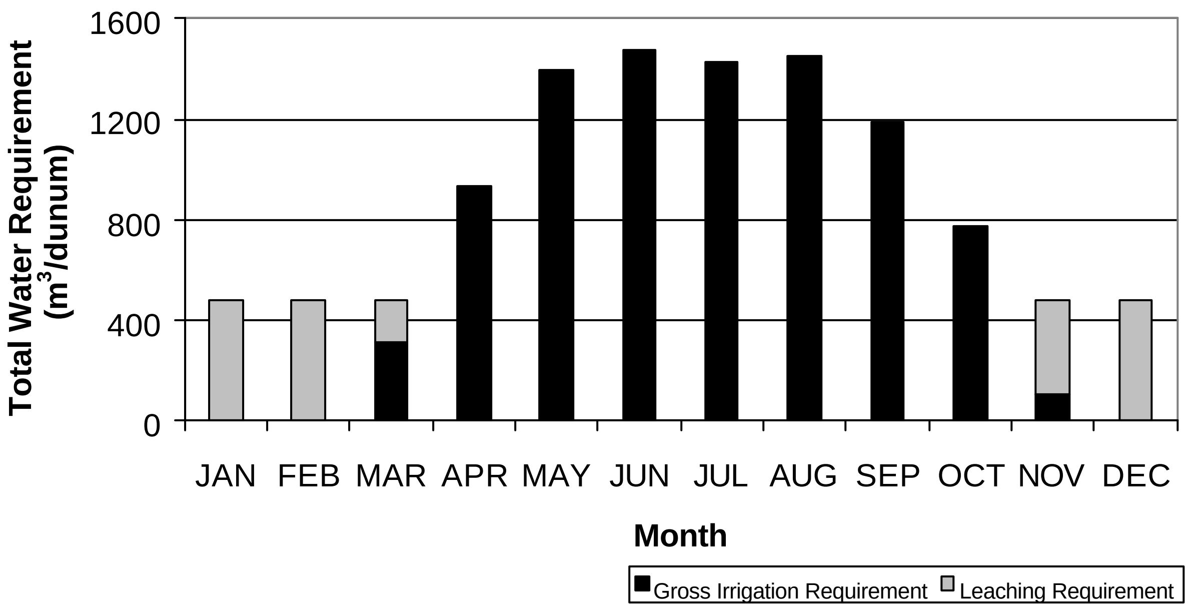


**Figure IV.1.** Gross irrigation and leaching requirements for each month

The gross irrigation and leaching requirements in the wadi (zone #7) are presented in Table IV.1.

**Table IV.1.** Gross irrigation requirement and leaching requirements per dunum for each month

| | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GIR** | **m^3/dn** | 0 | 0 | 31 | 93 | 140 | 148 | 143 | 145 | 119 | 78 | 10 | 0 | 907 |
| **Leaching** | **m^3/dn** | 48 | 48 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38 | 48 | 200 |
| **Total** | **m^3/dn** | 48 | 48 | 48 | 93 | 140 | 148 | 143 | 145 | 119 | 78 | 48 | 48 | 1,107 |

## IV.4. Conceptual Design

As mentioned above, the two basic variations for further development of irrigated agriculture in the wadi are:

1) Main conveyance pipeline, or lines, using the available slope in the wadi to deliver by gravity to riparian lands; and
2) As is presently practiced, convey the recycled water in the wadi, where individual farmers pump to their fields.

It should be noted that conveyance lines of the type proposed in 1) above, are generally complicated to operate, whether the outlets are operated by the farmers themselves (on-demand) or by the agency responsible for the pipeline.

A further variation would be diversion points along the wadi with shorter pipelines serving a number of land parcels. Although there may be some operational cost saving with such an approach over option 2 above (each farm has its own pump and line), the added complexity of multiple users will increase the risk of management difficulties.

### IV.4.1. Conveyance & Pumping

#### *IV.4.1.1. Main Pipeline*

To effectively reach potential plots on either side of the wadi would require a main line on each side of the wadi, or some form of siphon system crossing the wadi periodically. This is a relatively large undertaking. The estimated capital cost for such a facility to reach 80 percent of the irrigable land, including land presently irrigated by lifting from the wadi, is 15 M-JD, or 1,100 JD/dunum (11,000 JD/ha).

#### *IV.4.1.2. Individual Pumps from the Wadi*

This concept, which is presently practiced in the wadi, allows the individual farmer control over the water supplied to the farm. Furthermore, this does not require major civil works to bring the remaining irrigable area into production. Based on a typical farm of 200-dunnums, a static lift of around 50-m (TDH ~ 78-m), and a design flow rate of 22-lps, the capital cost for the pump, appurtent structures and facilities, and conveyance lines is around 12,000 JD per “farm”, which is less than 60 JD per dunum (600 JD/ha).

### IV.4.2. Storage

Because of the relative reliability of water supply in wadi Zarqa, significant on farm storage is not a requirement for irrigation in this area. However, as reported in Chapter II, many of the existing farms have a small on-farm reservoir.

### IV.4.3. Distribution System

The conceptual design of the distribution system, whether from a main conveyance line or multiple pumps and lines from the wadi, is based on an average farm unit of 200 dunums.

### IV.4.4. Application System

As detailed in Chapter II above, farmers presently irrigating with flood would rather use drip irrigation systems. The recommended application system for this option, as with the highlands options (MWI/ARD, 2000b), is drip. However, allowances should be made for irrigation of some of the crops with flood, particularly alfalfa and other field crops, which are important in the wadi.

### IV.4.5. Filters and Disinfection

Some farmers in the wadi use filters on their drip systems and others, preferring to put up with the maintenance of the system rather than the filters, do not. At present, disinfection is not practiced in the wadi.

## IV.5. Total Cost Estimate

From the above, the basic concept of pumping from the wadi is, by far, the least capital intensive option for conveying the water to the farm gate. The concept of a main conveyance line along the wadi is 18 times more expensive and, therefore, not considered further.

On farm costs have not been generated at this point, but will be similar to those developed for HL#2a in Shaner (2000).

## IV.6. Further Considerations

The remaining major concern, other than the cost, of this option would be the potential for further contamination of the groundwater with salts, nitrates and certain stable organic compounds in the recycled water, and the salts and agricultural residuals that would be leached from the soil profile.

Furthermore, this investigation has not, as yet, considered the issue of land ownership in the wadi and who the major beneficiaries would be if such developments were to be promoted.

## IV.7. Summary

The intensification and expansion of irrigated agriculture on the riparian lands in wadis Dhuleil and Zarqa have some merit, although the area available is limited to less than 3,000-dunums. The fragmented nature of the existing lands complicated the analysis of the land as to the extent and the sustainability of such a strategy, and the land tenure issues. Also, the present economic and regulatory enforcement situation, which would also apply for development of irrigated agriculture in the highlands, clearly limit the incentives for such developments.

Because this option is based on tried and proven practices, has relatively low lift (< 50-m) and conveyance costs, and needs limited storage facilities, it has significant advantages over other options.

For an irrigated area of 17,000-dunums, as is the case now, the total water requirement is estimated to be 19 M-$m^3$ per annum, rising to 22 M-$m^3$ per annum if all the “irrigable” land was brought into production. Some of this water demand is met by springs along the wadi.

# CHAPTER V
# WATER REUSE FROM
# OTHER AMMAN-ZARQA SOURCES

The other existing wastewater treatment plants in the Amman-Zarqa basin are Jerash (east), Abu Nuseir and Baq'a (MWI/ARD, 2000a). There are further wastewater treatment plants planned for Jerash (west) and for Zarqa, located downstream of the As Samra plant. The Zarqa plant is considered as part of water reuse associated with the As Samra plant in the main Wadi Zarqa and, therefore, has already been discussed in Chapter III.

The presented and expected quantities of treated effluent from these plants, as determined in MWI/ARD (2000a), are presented in Table V.1. along with the estimated area of land that could be irrigated with such volumes, using a gross crop water requirement of 1,340-mm after MWI/ARD (2000b).

**Table V.1.** Projection of total effluent to be discharged from the minor wastewater treatment plants in the Amman-Zarqa basin

| TREATMENT PLANT | | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|---|
| Jerash | (M-m$^3$) | 0.6 | 1.3 | 3.9 | 4.5 | 5.0 | 5.8 |
| | dunms | 450 | 970 | 2,910 | 3,360 | 3,730 | 4,330 |
| Abu Nuseir | (M-m$^3$) | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 | 0.8 |
| | dunms | 370 | 370 | 450 | 520 | 520 | 600 |
| Baq'a | (M-m$^3$) | 3.8 | 5.3 | 8.4 | 9.7 | 10.9 | 12.4 |
| | dunms | 2,840 | 3,960 | 6,270 | 7,240 | 8,130 | 9,250 |
| **TOTAL** | **(M-m$^3$)** | **4.9** | **7.1** | **12.9** | **14.9** | **16.6** | **19.0** |
| | **dunms** | **3,660** | **5,300** | **9,630** | **11,120** | **12,390** | **14,180** |

## V.1. Present, Planned & Potential Water Reuse

This section presents a summary of present water reuse activities at each of the three minor plants in the basin, and any plans for further develop of water reuse from these three sources and the planned facility at Jerash West. Also, further water reuse potential developments at each of the sites are presented and discussed.

### V.1.1. Jerash

The effluent from the wastewater treatment facility is discharged into Wadi Al Wadana. The bulk of this water is diverted from the wadi to one relatively large farm. Very little water reaches Wadi Zarqa. Farmers in the vicinity of the plant and further downstream of it receive fresh water from Qairawan spring delivered through a small concrete canal.

From the interpretation of the satellite imagery (see Appendix C), the total irrigated area in the wadi is approximately 2,000-dunnums, with, according to the analysis, equal representation of vegetables, alfalfa and olives, and a smaller area of other tree crops. It should be noted, however, that there are a number of nurseries for ornamental plants on the right bank of the wadi, which are interpreted as "vegetable" crops. The mixture of fresh and recycled water use in the wadi makes it difficult to determine which crops are grown with the recycled water.

The farm which presently diverts the bulk of the effluent from the wadi grows 130-dunnums of citrus and a further 60-dunnums of pistachios. The farm manager, a professional agricultural engineer, recognizes the impact of the salinity on the yield of the citrus. This is a well-managed enterprise, and could serve as a model for similar enterprises at other reuse sites.

There is no space at the wastewater treatment facility to develop irrigated agriculture on-site with the recycled water. Downstream the wadi is narrow and steep-sided with little room for further development. However, the areas upstream of the treatment facility are presently irrigated with spring water, and present a potential opportunity for exchange, thereby freeing up fresh water for domestic use. In fact, the spring upstream has already been developed for domestic water supply.

As mentioned above, the volume of effluent (0.6 M-$m^3$ per annum) is used. If all 2,000 dunums were to be irrigated, then, based on the water requirements presented in Table IV, the total demand for water would be around 2.2 M-$m^3$ per annum, which according to the projections in Table V.1, could be satisfied in 6 or 7 years from now.

### V.1.2. Abu Nuseir

The effluent from the wastewater treatment facility is discharged into Wadi Al Marbat. It eventually reaches Wadi Zarqa via the Badran and Al Khilleh Wadis. The effluent leaves the facility through a small earth ditch leading to the main course of the wadi. There are no agricultural activities immediately downstream (see Appendix C) of the plant, and much of the area is being developed for urban use.

The only water reuse activity is a small pilot study within the facility, which is being conducted by a university student investigating tomato's response when using fresh water, effluent and blended water in different ratios. JICA (2000) identified a potential reuse site of around 850-dunums downstream of the plant, and proposed growing olives and forest trees. There is no space at the facility to irrigated agriculture on-site with the recycled water. The projected effluent volumes at this facility (see Table V.1., will not fully irrigate this area.

### V.1.3. Baq'a

The effluent from the wastewater facility is discharged into a 7-km long pipeline, which discharges into Wadi Rumman, and, in turn, to King Talal Reservoir. According to the facility manager, the effluent is not used for irrigation immediately downstream of the plant. Those farmers that are growing trees reportedly haul in water, and are not willing to use the treated effluent. However, some farmers immediately downstream of the discharge point of the pipeline are utilizing the effluent for growing mainly olive trees. Farmers have approached the facility manager to use the effluent in the wadi for growing alfalfa. The satellite imagery (Appendix C) confirms that there is little, if any, irrigation in the immediate vicinity of the plant.

There is no present plan to use treated effluent near the plant, or to expand use at the pipeline outfall (JICA, 2000), and that the effluent should continue to be discharged to KTR.

There is limited space for the development of irrigated agriculture at the plant and immediately downstream. However, east of the Baq'a wastewater treatment plant is a major irrigated area producing fresh vegetables. The water source for this area is groundwater. This presents a potential opportunity for exchange of recycled water, thereby freeing up fresh water for domestic use. Clearly there are many important issues with such a development, including the potential threat to the groundwater, the marketing concerns, the impact on cropping patterns and the acceptability by the present users. However, the value of the groundwater would justify investment in further treatment of the wastewater, farmer education and so forth. The presently irrigated area is around 4,000 dunums. Although not all of this could be exchanger, there are lands for further development of irrigated agriculture. It is estimated that such a project could reach around 2,000 dunums (2.2 M-$m^3$) by the year 2005, and a maximum of 4,000 dunums (4.4 M-$m^3$) by the year 2010.

### V.1.4. Jerash West (Planned)

The Jerash West is planned for development around 2006 - 2008 (MWI/ARD, 2000a). With limited land for irrigation in Wadi Al Wadana, it is presently proposed that the effluent will be discharged into the wadi and allowed to flow to KTR (JICA, 2000).

## V.2. Summary and Projected Demands on Water

Following field visits to each of the minor wastewater treatment plants (Abu Nuseir, Baq'a and Jerash), interviews with farmers in the downstream wadis and examination of the relevant satellite images (see Appendix C), the majority of the effluent from these plants makes its way to KTR via the wadis. The major exception is at Jerash.

At present, any effluent from the minor wastewater plants in the Amman-Zarqa basin, which is not used in the wadi downstream of the plant, or lost to evapotranspiration or percolation, flows to King Talal Reservoir. Relative to As Samra, these contributions are small, but they are significant. It is assumed that future developments of reuse would be based on the projected increases (MWI/ARD, 2000a) in effluent volumes from these plants.

Opportunities for developing irrigated agriculture based on recycled water do exist downstream of Abu-Nuseir and Bac'a, but not at Jerash. Any proposed water reuse with this effluent will be competing with the present and future demands in the Jordan Valley. In the longer term it is possible that the total volume of effluent generated in the Amman-Zarqa Basin will mean that new demands need to be created. However, this appears to be unlikely in the short to medium term. Also, the further ad-hoc development of using effluent from the wadi, such as downstream of the Baq'a effluent conveyance pipeline, will likely have the same enforcement difficulties that presently exist in Wadi Zarqa.

Two potential developments merit further examination. These are: Baq'a Recycled Water Exchange Project, and Jerash Recycled Water Exchange Project. The water d emands for these developments, along with those for Abu Nuseir are compared with those for no further development in Table V.2.

**Table V.2.** Expected recycled water requirements at the minor wastewater treatment facilities for scenario without further development, and scenario with development.

| WWTP | WATER REQUIREMENTS | | | | |
|---|---|---|---|---|---|
| | Present | Future w/o | Future with | | |
| | | | 2005 | 2010 | 2025 |
| Abu Nuseir | 0 | 0 | 0.4 M-m$^3$ | 0.45 M-m$^3$ | 0.6 M-m$^3$ |
| Baq'a | 0 | 0 | 2.2 M-m$^3$ | 4.4 M-m$^3$ | 4.4 M-m$^3$ |
| Jerash | 0.6 M-m$^3$ | 0.6 M-m$^3$ | 1.3 M-m$^3$ | 2.2 M-m$^3$ | 2.2 M-m$^3$ |
| Jerash West | 0 | 0 | 0 | 0 | 0 |

# CHAPTER VI

# CONCLUSIONS & RECOMMENDATIONS

## CONCLUSIONS

The health-based cropping restrictions in the wadi are not fully enforced. Approximately 4,000-dunums of vegetables are grown in the vicinity of the wadi water, which is mainly comprised of effluent. In addition to the real risks, the perception to the general public jeopardizes the domestic and export markets.

Although further land (3,000-dunums) could be developed for irrigation in the wadi, much of this was historically irrigated, and would come back into production if markets improved and health-based cropping restrictions were lifted. Using the wadi for conveyance and pumping to each farm separately is, by far, the least expensive option.

Land for the further development of irrigated agriculture is also constrains reuse from the minor wastewater treatment plants. However, both Baq'a and, to a lesser extent, Jerash present potential opportunities for exchanging recycled water for fresh water sources. Detailed feasibility studies are required.

## RECOMMENDATIONS

### Reduce Misuse of Recycled Water In Wadi Zarqa & Tributaries

The present ban on any vegetables or fruit that are not grown on trees should be extended to all riparian lands in wadi Zarqa and to the side wadis with a wastewater treatment plant upstream, no matter what the water source.

When the fecal coliform levels in the wadi are reduced to comply with the Jordanian Standards (below 1000-MPN), the growing of vegetables and fruit to be eaten cooked could be allowed, thereby allowing farmers, particular small-scale operations, further opportunities to make a positive return.

The reduction of fecal coliform in the wadi requires implementation of the new facilities at As Samra, and implementation of a plan to comprehensively control other sources of micro-biological contamination to the wadi. The investigation of these other sources of micro-biological contamination is an urgent requirement.

### Improving Economic Returns from Water Reuse In Agriculture

Provide farmers with more information on crop selection with respect to the quality of the wadi water, such as the negative impact of the salts and chlorides on the citrus and stone fruits. Develop recommendations on crops and specific varieties that will provide good returns with the quality of water anticipated in the wadi.

**Replacement of Fresh Water Presently Used For Agriculture**

Investigate and, if found to be feasible, implement exchanges of recycled water from the minor wastewater treatment facilities, for groundwater and/or spring water presently used for agriculture. The two main areas to be investigated are Bac'a and Jerash.

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# APPENDIX A

## QUESTION GUIDELINES FOR FARM VISITS

This appendix contains the form that was used as a guide for conducting field visits in wadi Zarqa and side-wadis. This form was completed for 41 farms, in total, 27 of which were in a position to use water that had originated from the As Samra wastewater treatment plant.

| S I T E & F A R M E | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **SITE** | Date of Visit | | Coordinates | Jordan East | | Jordan North | | Interviewer | | |

| **FARMER** | Name of Owner | | Name of Respondent | | Farm Leased | | Farm Size (Dunums) | Irrigated Area (dunums) |
|---|---|---|---|---|---|---|---|---|
| | | | | | Y | N | | |
| | Respondent Position | | | | | | | |
| | Owner | | Tenant | | | | | |
| | Manager | | Other | | If sharecropper, % of farm sharecropped | | | |
| | Laborer | | Share-cropper | | | | | |

| W AT E R S UP P L Y & S T O R A GE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| What is the source(s) of your irrigation water? | Wadi Zarqa | Wadi Dhuleil | Wadi _____ | Groundwater | Spring | Truck | Other | |
| How much water do you typically use each year from each source? | | | | | | | | |
| Is this enough water? | | | | | | | | |
| What is the quality of the water from each source? | Good | | Limited | | Poor | | V. Poor | |
| What is the power source for pumping (diesel, electricity, etc.)? | Electricity | | Diesel | | | | | |
| Do you filter the water from the source? | Yes | | No | | | | | |
| Do you have on-farm storage? | Yes | | No | | What is the volume of storage? | | | |

| QUALITY | Specific problems with the quality of water from the Wadi? |
|---|---|
| | 1) |
| | 2) |
| | 3) |
| | 4) |
| | 5) |
| | 6) |
| | NOTES: |

**CROPS & CROPPING**

| What are your major crops (list at least five) and the area planted? | | What were your major crops (list at least five) and the area planted before the water quality deteriorated? | |
|---|---|---|---|
| MAJOR CROP | AREA | MAJOR CROP | AREA |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

| APPLICATION SYSTEM | | | | | | FARMING PRACTICE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SYSTEM | AREA | SYSTEM | AREA | SYSTEM | AREA | PRACTICE | AREA | PRACTICE | | | AREA |
| Drip | | Furrow | | Sprinkler | | Open field | | Open field with mulch | | | |
| Flood | | Other | | | | Tunnels | | Green houses | | Other | |

**G E N E R A L**

| What are your two main soil problems? | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Salinity | | Poor Drainage | | Heavy Soils | | Low Fertility | | No Problem | |

| Do farmers in this area use water from Wadi Zarqa to irrigate crops that will be eaten raw? | Yes | | No | |
|---|---|---|---|---|

| What are your major problems with irrigation/water management? | Notes: |
|---|---|

| If there is more water flowing in the wadi would you: | |
|---|---|
| Put more water on your existing crops | |
| Grow different crops | |
| Expand the irrigated area | |
| Do nothing | |

| If the water in the wadi smelled and looked better would you plant different crops? | Y | | N | |
|---|---|---|---|---|

Notes:

# APPENDIX B

## SUMMARY OF RESULTS FROM FARM INTERVIEWS

The data summarized here are from those farms [27 interviews], which have access to water from wadi Dhuleil and the main wadi Zarqa downstream of As Samra. In other words, potentially using effluent from As Samra.

**Table B.1.** Summary of data on farm, irrigated and cropped areas.

| | TOTALS dunums | AVERAGE dunums | PROPORTION % |
|---|---|---|---|
| Farm area | 11,644 | 431 | |
| Irrigated land[1] | 5,341 | 198 | |
| Olives | 2,195 | 81 | 41% |
| Citrus | 152 | 6 | 3% |
| Alfalfa | 142 | 5 | 3% |
| Vegetables | 1,119 | 41 | 21% |
| Field crops | 230 | 8 | 4% |
| Other trees | 797 | 30 | 15 % |
| Unaccounted | 706 | 26 | 13% |

**Power source for pumping?**

Diesel - 23
Electricity - 2

**Table B.2.** Responses to yes/no questions.

| | YES | NO |
|---|---|---|
| Farm leased? | 11 | 16 |
| Enough water in wadi?[2] | 15 | 12 |
| Filter irrigation water? | 7 | 20 |
| On farm storage? | 9 | 18 |
| Other farmers misuse wadi Zarqa water?[3] | 6 | 21 |
| Water smelled & looked better, plant different crops? | 19 | 6 |

[1] Most farmers reported that they used to irrigate more land before, but, because of the contamination of the wadi, they can no longer grow vegetables

[2] If the wadi was the source, then they reported that quantity was always sufficient

[3] For all the farmers in this sample, if they were irrigating vegetables they reported the source of water to be groundwater or spring. If they were irrigating trees or field crops, including alfalfa, they reported using the wadi as the water source.

**What is the quality of the water from their sources?**

14 (Good). 7 (limited). 4 (poor). 5 (very poor).

Those answering good or limited were invariably using water from wells or springs, whereas those responding poor or very poor were using wadi water. Some of the farmers reported salinization problems with their spring and well water.

**Specific problems with the quality of water from the wadi?**

Most farmer's issues with the water from the wadi were that it smelled bad, and that it brought insects, pests and diseases.

**Application systems?**

| | |
|---|---|
| Drip - | 8 |
| Flood - | 19 |

Flood applications systems generally consisted of the water being pumped from either the source or the on-farm reservoir and water by means of regular pipe. Actual conveyance of water along the surface of the soil, which is usually the case with flood system, is not a component of these systems.

**Farming practice?**

| | |
|---|---|
| Open Field - | 20 |
| Open Field with Mulch - | 4 |
| Green houses - | 3 |

**Main soil problems?**

| | |
|---|---|
| Salinity - | 8 |
| Low fertility - | 1 |
| No problem – | 13 |
| Sandy soil - | 3 (low water holding capacity) |

A few also mentioned diseases in the soils.

**Problems with irrigation water management?**

Most farmers using flood indicated that they would like to convert to drip systems, but they can't because of the high cost of this application system.
Those with drip system responded that their main water management issue was with clogging of the system.

# APPENDIX C

## CLASSIFYING IRRIGATED AREAS WITH SATELLITE IMAGERY

This appendix reports on the efforts to use Landsat-7 satellite imagery to classify irrigated areas in Wadis Dhuleil and Zarqa. The objectives of this were to:

- Estimate the total area irrigated area within the wadis, and
- If possible, determine the total area and, therefore the importance, of irrigated vegetables.

A further objective was to assess whether such techniques may have some merit in monitoring crop production, specifically the growing of vegetables illegally with recycled water.

The area of interest is the riparian lands of Wadis Dhuleil and Zarqa between the As Samra wastewater treatment plant and the King Talal Reservoir, and the side wadis.

It was realized at the outset that the accuracy of the results would be relatively low. In contrast to the highlands (MWI/ARD, 2000), the irrigated lands are comprised of relatively small parcels of around 20 dunnums or less. Given the same resolution of the satellite images, delineation of the various classes selected is, therefore, inherently less accurate.

**Approach and Results**

Landsat-7 scene 174-38 of August 1999, which covers an area of 180 by 120-km, was cropped to the limits of the area of interest (see Figure C.1.).

Initially unsupervised classifications were attempted, followed by supervised classifications with general information on crops and vegetation, and, finally, supervised classification with training sets from irrigated areas on the riparian lands.

Because of the increased natural vegetation towards the wetter west of the area of interest the initial attempts at unsupervised classifications resulted in substantial misclassifications. However, the results generated were used to conduct further phases of these investigations and the field interviews (see Appendices A and B).

The supervised classifications proved to produce reasonable results, both in distinguishing between natural and irrigated vegetation, and in distinguishing major sub-classes of irrigated crops.

**Figure C.1.** Cropped Landsat-7 scene 174-38 of August 1999

An initial understanding of the area was developed from team members visiting the area (see Appendices A and B). From this, the distinction between natural vegetation and irrigated areas was made. Further field visits were conducted to develop training sets, specifically to determine the sub-classes of irrigated crops. The key to the classes is shown in Table C.1.

**Table C.1.** Classes in supervised classification.

| CLASS | COLOR |
|---|---|
| Alfalfa | Bright Green |
| Soil & Rocks | White |
| Grass | Yellow |
| Vegetables | Red |
| Water | Blue |
| Urban | Grey |
| Other Trees | Brown |
| Olives | Forest Green |

The subsequent supervised classification generated the results shown in Figure C.2. Using these results, statistics were generated for the "riparian lands" (area within 200-m of the centerline of the Wadi), extending from As samra (including the area in the immediate vicinity of the facilities) to KTR (see Table C.2.). Statistics were also generated for the riparian lands in the "Upper" Wadi Zarqa, Wadi Quneia and Wadi Jerash (Table C.2.).

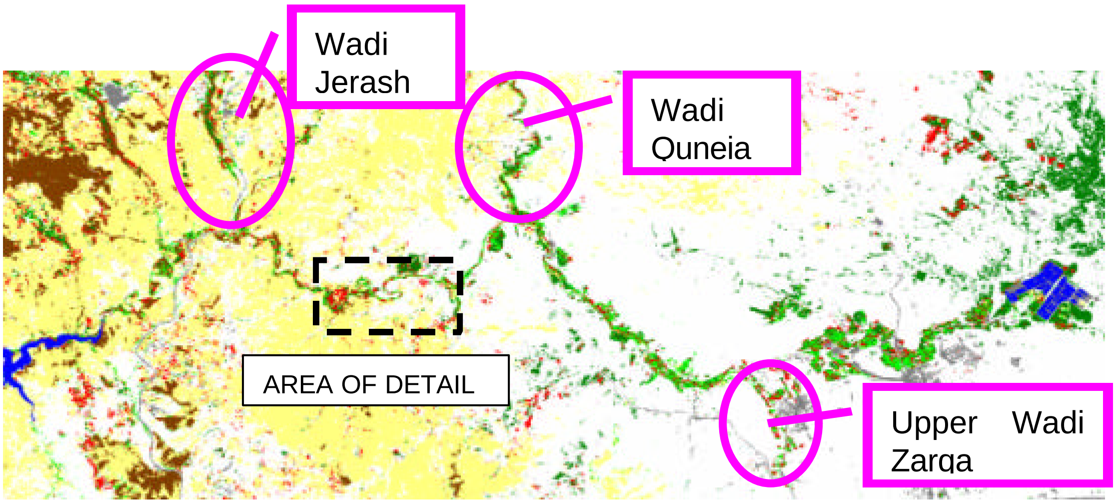


**Figure C.2.** Results of supervised classification

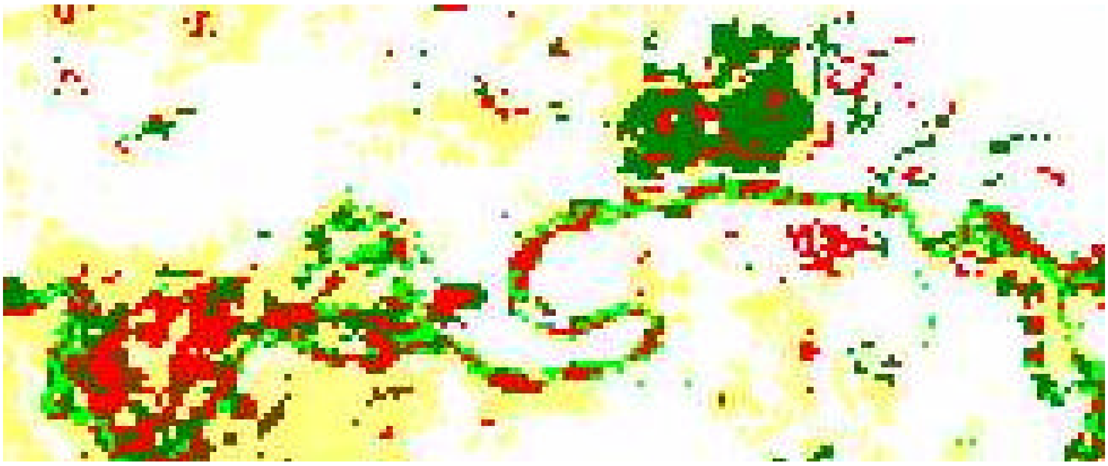

**Figure C.3.** Example of detail from supervised classification.

**Table C.2.** Sub-classification of irrigated crops in the Wadis

| | WADI | | | | |
|---|---|---|---|---|---|
| | Dhuleil & Zarqa | Upper Zarqa | Quneia | Jerash | All |
| Vegetables | 4,412 | 400 | 296 | 595 | 5,702 |
| Alfalfa | 5,354 | 318 | 364 | 601 | 6,638 |
| Olives[4] | 6,209 | 188 | 448 | 565 | 7,411 |
| Other Tree Crops [5] | 1,319 | 0 | 19 | 279 | 1,618 |
| **Total** | **17,294** | **906** | **1,127** | **2,040** | **21,369** |

Natural vegetation is a composite of both grasses and forest trees. Within the riparian lands the naturally growing trees and the irrigated fruit trees have a similar signature, therefore, the "other tree crops" include both within the riparian lands. Also, the olive trees include both those irrigated and non-irrigated, especially towards the west of the area of interest, where precipitation is higher.

## Conclusions

Noting that the above results are approximate, the total area of presently irrigated land which could be using water from As Samra wastewater treatment plant, extends to around 17,000-dunnums (1,700-ha), of which roughly 4,400-dunnums (440-ha) or 26 percent are in vegetables.

## Further Work

In the future, the use of SPOT imagery data fused with Landsat data would enhance the resolution, allowing improved accuracy of delineating the training sets on the image. Furthermore, the infrared band in SPOT, and the three infrared bands in Landsat may further enhance vegetation classification. Such improvements may allow remote sensing to be used as a monitoring tool in Wadi Zarqa and the Jordan Valley.

The remaining scenes (May 2000 for LandSat 7, and April 1998, October 1999 and April 1999 for LandSat5) covering the area of interest could have training sets developed to examine seasonal changes in cropping activities.

This analysis could be extended to the Jordan Valley to develop the same statistics for the three major directorates. The images already purchased cover the entire Jordan portion of the Jordan Valley.

4 Includes irrigated and rain-fed olives
5 Includes fruit trees and forest trees on riparian lands